# Horizontal Branch Morphology in Galactic Globular Clusters: Dense Environment is "a" Second Parameter

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## ABSTRACT

The Horizontal Branch (HB) morphology in the color – magnitude diagram of the Galactic globular clusters depends on many factors, and it is now firmly established that the so-called "Second Parameter" is not just the cluster age as claimed for several years.

As a part of a wider program devoted to the search for the physical processes driving the Horizontal Branch Morphology, we re-address here the problem of the extension of blue HB tails by introducing a new quantitative observable, $B2/B + R + V$ , where $B2 = \{Number\ of\ HB\ stars\ with\ (B - V)_0 < -0.02\}$.

We demonstrate that the environmental conditions within a cluster clearly affect its HB morphology, in the sense that, in general, the higher the cluster central density the higher is the relative number of stars populating the most blue region of its HB.

## 1. Introduction

The so-called *Second Parameter* ( $2^{nd}P$ ) effect in the classification of the Horizontal Branch (HB) morphology of Galactic globular clusters (GGC's) is a long-standing problem in stellar astrophysics (see Zinn 1993, Fusi Pecci et al. 1993, Lee, Demarque and Zinn 1993, hereafter LDZ, Catelan and de Freitas Pacheco 1994, Peterson et al. 1995, Stetson et al. 1996, Fusi Pecci et al. 1996a for recent reviews). The name originates from the observation that at least one parameter other than metallicity (the classical *first parameter*) has to affect the HB star distribution in color (and thus, temperature) in the Color-Magnitude Diagram (CMD).

The understanding of which parameters and to what respective extent they generate the observed HB morphologies has an ubiquitous impact on many astrophysical topics, ranging from stellar evolution (see Renzini and Fusi Pecci 1988 and D'Cruz et al. 1996 for useful references) to galaxy formation and evolution (Majewski 1993, Fusi Pecci et al. 1995, Zinn 1996).

Due to the success of the "Searle and Zinn" scenario for Galaxy formation (Searle and Zinn 1978, hereafter SZ; LDZ, Zinn 1993, Zinn 1996), the consensus on the hypothesis that *the age is the only dominant $2^{nd}P$ in the Galactic Halo* has continuously grown in the last years. However, it is important to stress that while this idea seems to have been a very fruitful base for the interpretation of a number of observational evidences in the SZ framework, a clear-cut direct confirmation of the hypothesis is still lacking (see Fusi Pecci et al. 1995).

Furthermore, many authors have argued that the variety of observed HB morphologies cannot be entirely (and *globally*, in the sense defined by Lee 1993) described in terms of metallicity and age (Fusi Pecci et al. 1996a and references therein), and now at least one firm evidence in this sense has come out from recent HST observations (Stetson et al. 1996). We will present a detailed discussion of the $2^{nd}P$ effect, within the framework coming out from the latest results, in a dedicated paper (Fusi Pecci et al. 1996b, hereafter F96, in preparation). Some anticipations can be found in Fusi Pecci et al. 1996a.

In this note, in particular, we deal with the problem of putting into clear-cut evidence the connection between stellar-density conditions in globulars and the presence and extension of *blue tails* (Castellani 1994) in the Horizontal Branches of their CMDs, an idea we originally put forward about ten years ago (BCFP85, Fusi Pecci 1987) and that nowadays seems ever more worth of detailed study. Relevant indications about the existence of such a connection have already been presented by our group (F93) but they *(a)* were based on set of HB morphology parameters that are hard to measure in many clusters, and *(b)* were possibly subject to a spurious effect described by van den Bergh and Morris (1994).

Based on a new parametrization, which clearly overcomes both the quoted problems, we put on a firmer and quantitative ground the results of F93, and we show that the relative number of stars populating the HB blue tails is strongly correlated to the cluster central density.

## 2. Parametrizing HB morphology: the blue tails

One of the main difficulties in studying the HB star distribution is to provide a satisfactory, quantitative, description of its morphology (see Buonanno and Iannicola 1994). As well known (Rood and Crocker 1985), the problems arise mainly from the fact that in the traditional (V, B-V) or (V, V-I) planes the blue HB tails are actually "vertical", mostly due to the increasing bolometric correction with decreasing color index (Rood and Crocker 1989, F93). Furthermore, even if the HB star distribution were to be Gauss function or some other unimodal function (Rood 1973), to yield a complete quantitative description one must know the location of the peak and some kind of dispersion around it, *i.e.* two parameters at least (Dorman 1995).

For instance F93 noticed that the most widely used HB morphology parameter, $B - R/B + R + V$ (Zinn 1986, Lee 1989) –where B, V, and R are the HB populations bluer, within, and redder than the HB instability strip, respectively– is useful in ranking the various HB distributions according to the positions of the their peaks (see also LDZ), but it is almost insensitive to any variation of their extension. In particular, it is completely unable to distinguish *(a)* between distributions which have similar peaks but very different blue tail populations and *(b)* between distributions that lie only in the region of the CMD which is bluer than the instability strip (see also Dorman 1995).

With the aim of circumventing this problem, we (F93) proposed some "quite crude" empirical observables ($BT$ and $L_t$ –the lengths of the blue tails and of the whole HB distributions, measured in arbitrary units) devoted to rank the observed HB's and their blue tails according to their color[3] extension. We believe this additional information to be of fundamental importance. In fact, while the location of the peak of the HB distribution in color presumably reflects the effects due to basic "average" parameters (metallicity, age, mean mass loss, etc.) common to all cluster members, the spread around it yields a *direct* measure of the spread in total mass loss and/or core mass (eventually due to unknow mechanisms, like for instance spread in core rotation, special mixing, tidal stripping, etc.). It seems very likely that the two items are strictly connected, and any quantitative observational study of the color spread and of its possible correlation with any cluster parameter could set valuable constraints on the whole "mass loss affair" and, in turn, on the $2^{nd}P$ –problem.

## 2.1.  Definition of a new index

Using the quoted parameters, F93 found that the color extension of the HB distribution is correlated with cluster central density $(\rho_0, L_V/pc^3)$, in the sense that more centrally concentrated clusters tend to have bluer HB-morphologies and often present extended blue HB tails (see also Castellani 1994). van den Bergh and Morris (1994, hereafter vdBM) have questioned this result, suggesting that "the apparent correlations between the length of the HB and the cluster luminosity and density may be affected by observational bias". In particular, because of the clear correlation existing between luminosity and central density (Djorgovski and Meylan 1994), in their view the correlation found by F93 could be a spurious effect reflecting the fact that "one can trace HB's over greater lengths in rich clusters than in poor ones".

To examine the criticism raised by vdBM and to obtain quantitative information on the blue tails not affected by the quoted possible bias (hereafter *vdBM-bias*), we define the index $B2/B + R + V$ as the ratio of the number $B2$ of observed HB stars bluer than $(B - V)_0 = -0.02$, to the number of all the stars belonging to the HB distribution, $B + V + R$. Further operative details can be found in the preliminary reports by Buonanno (1993), Buonanno and Iannicola (1994) and Fusi Pecci et al. (1996a).

Being normalized to a quantity directely related to the total luminosity of the sampled population (Renzini and Fusi Pecci 1988), $B2/B + R + V$ is necessarily free from the quoted *vdBM-bias*. Nevertheless, for sake of checking and recalling also the caveats put forward by Ferraro, Fusi Pecci and Bellazzini (1995), a wide set of simulations have been performed to test the variation of $B2/B + R + V$ with the cluster integrated luminosity. These simulations show that, for any fixed "realistic" couple of the peak and of the standard deviation of the distributions (assumed to be Gauss functions), $B2/B + R + V$ turns out to be insensitive to any change of the cluster total luminosity within the range actually spanned by Galactic globulars (*i.e.* , $-4 \leq M_V \leq -10$; more details about the simulations will be given in the forthcoming paper F96).

Beside $B2/B + R + V$ defined above, we will use below also another parameter, $(B - V)_{peak}$ , defined and measured by F93 to determine the actual location (in $(B - V)_0$) of the peaks of the HB stellar distribution. F93 already showed that this observable strongly correlates with $B - R/B + R + V$ , and substantially yields similar basic information.

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## 3.  Database and results.

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[3]Actually, it is not precisely the "color", as in the $(V, B - V)$ plane the blue HB ridge-lines are not $V \simeq const$ straight lines. In fact they are curves, with the star temperature increasing along the "red-to-blue" direction. F93 tried to trace the covered ranges in temperature, by measuring the extension of the curve ridge-lines themselves.

### 3.1. The HB data

Our complete database collects 63 halo globular clusters for which the new HB parameters can be measured on the basis of available photometric studies. The entries are limited to clusters with $[Fe/H] < -1.0$ because the observed clusters with higher metallicity all have very red, stubby HB's. This is due to the very non-linear response to mass loss by stars in different metallicity regimes (see F93, Figure 1,2 and DDRO, Figure 6 and the discussion therein). In fact, according to the current standard and canonical HB models, a star with such a high metal content need to lose as much as $\sim 0.3 M_\odot$ to be located in a ZAHB position bluer than the instability strip. This same phaenomenon strongly limits the capability of a metal rich population to produce blue HB stars (but see sect. 4). Since our index is devoted to study blue morphologies and it is "blind" to very red ones, the inclusion of the metal rich cluster in the sample would have been nonsense.

The database is presented in Table 1, whose first column reports the identification number or name of the clusters. Metallicities ($[Fe/H]$ , $2^{nd}$ col.) and central densities ($\log \rho_0$ , $3^{rd}$ col.) are taken from Djorgovski (1994). The de-reddened colors of the peak of the HB-distributions ($(B-V)_{peak}$ , $6^{th}$ col.) are drawn from F93 (44 entries). The new HB-morphology index $B2/B+R+V$ , listed in the $4^{th}$ column for all considered clusters, has been obtained by star counts on the CMDs referenced in the $7^{th}$ column. As an independent check we calculated also the parameter $B-R/B+R+V$ , and found excellent agreement with the counts of LDZ.

A fully reliable extimation of the uncertainties affecting indexes as $B-R/B+R+V$ or $B2/B+R+V$ is an almost unaffordable task. In fact this kind of indexes suffer the effects of three main indeterminacy souces: (i) the Poisson noise related to star count statistics, and in turn to the number of sampled stars; (ii) the precision of the photometry; note that this item is particulary difficult to deal with when a large set of measures are collected from different photometric studies, each with a different photometric precision; (iii) completeness problems. At present, the only attempt to extimate $B-R/B+R+V$ errors has been made by LDZ which, based on synthetic HB calculation, find only "...estimates of the uncertainty due to the random distribution of stars along the evolutionary tracks" and assume that this figure is nearly half of the total uncertainty affecting the measures of the index. Since the error source described at item (i) above, is the only one which can be somehow controlled from an empirical point of view, we prefer to list the quantity $\frac{\sqrt{B+R+V}}{B+R+V}$ (Tab. 1, $5^{th}$ col.) which ranks all $B2/B+R+V$ entries according to the total number of sampled HB stars. These figures are just indicative of the quality of the population sampling, and are not intended to describe also the photometric quality and/or completeness of the sample.

Actually, the determination of precise errors is not so crucial for the present purposes as we are not aiming at deriving any physical quantity from our indexes. We rather use them as a statistical data-set against which to test the likelyhood of a particular hypothesis, i.e. to estimate the probability that a given correlation and/or association can be originated just by chance.

### 3.2. Dense environment and blue tails

In order to search for a clear-cut evidence of the link possibly connecting intrinsic structural parameters of the considered clusters to existence and extension of the blue HB tail, we divided the available sample into two groups:
- HD-group: *high density* clusters, with $log\rho_0 > 3$ (37 objects)
- LD-group: *low density* clusters, with $log\rho_0 \leq 3$ (26 objects).

We performed a Kolmogorov-Smirnov test to verify whether the two groups display distributions in $B2/B+R+V$ which are compatible with drawing them from the same parent population. *The probability that the two sub-groups are extracted from the same parent population in $B2/B+R+V$* turns out to be 0.02%. Figure 1 (left panel) shows that the distribution of the LD-group is significantly skewed towards low values of $B2/B+R+V$ . In fact, 85% of the sample have $B2/B+R+V \leq 0.2$. At the same time, it is particular worth noting that *the two sub-groups of clusters have indistinguishable metallicity distributions* (Figure 1, right panel). This ensure that the above result is free from any spurious effect due to sampling in metallicity.

As a first conclusion, we can thus say that Figure 1 shows *direct* evidence (in the sense that it is fully "model-independent") that *clusters having the same metallicity, but different intrinsic concentrations behave differently as far as "blue" HB morphology is concerned* and, more specifically, *stars harboured in very dense cluster environments have higher probability to populate the most blue side of the Horizontal Branch distribution in a CMD*.

Our analysis can now be pushed a bit further. We have already noted that the index $B2/B+R+V$ presumably depends not only on the extension of the blue side of the HB distribution but could also be somehow influenced by the position of the peak. The main reason why this is expected to occur is very simple: given two unimodal distributions with
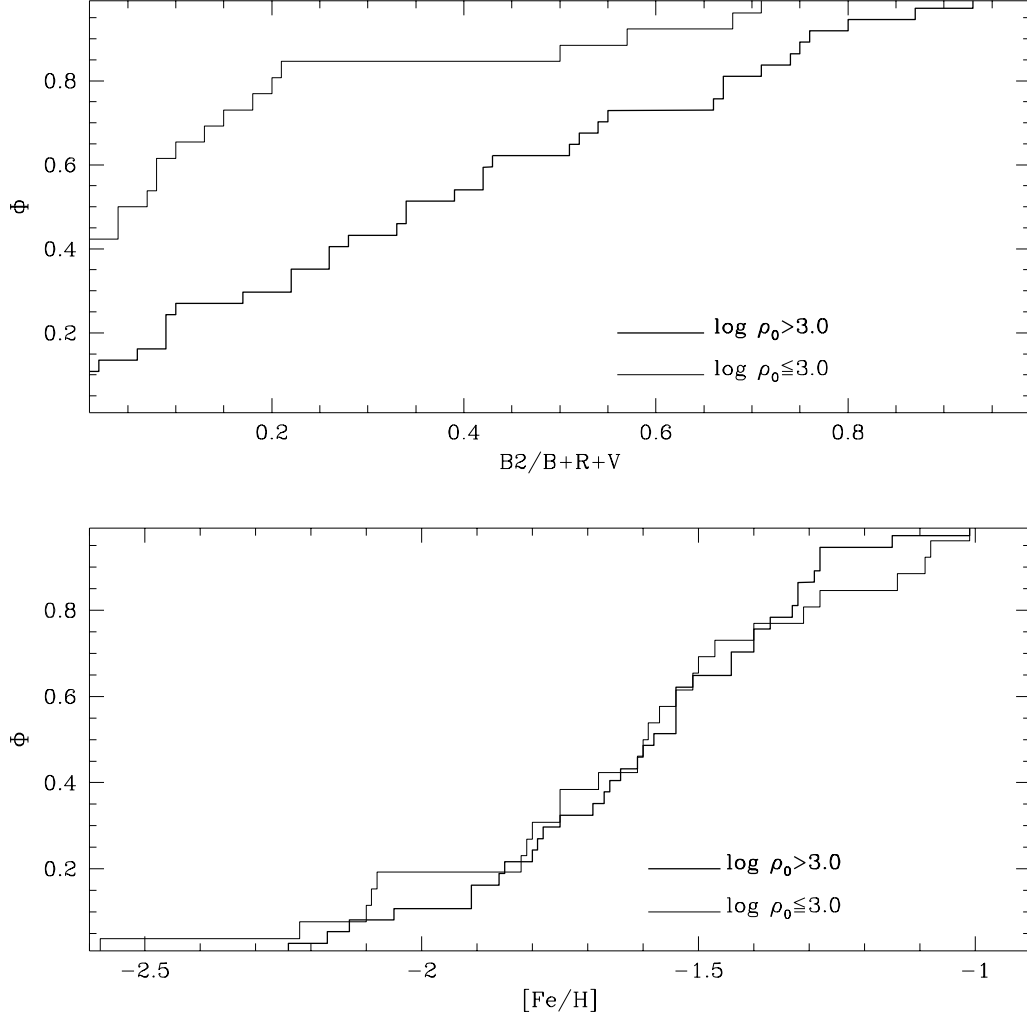
Fig. 1.— Upper panel: the cumulative distribution of the $B2/B + R + V$ index for the High Density group (thick line) compared to that for Low Density group (thin line), see Sect. 3.1. The HD-group distribution is significantly skewed towards higher values of the $B2/B + R + V$ index with respect to the LD one. Lower panel: (same graphic labels) the cumulative metallicity distribution of the two groups are undistinguishable.

the same color spread, the number of stars falling blueward of the $(B - V)_0 = -0.02$ will be higher for the distribution that display the "bluer" peak. Hence, it is worth trying to disentangle the two dependences, making use also of the $(B - V)_{peak}$ parameter. By doing this, we simultaneously test our suggestion that the "dense environment effect" mostly acts on the spread of the distribution, rather than on the HB peak. If we assume that the peak reflects the *mean* properties of the HB distribution, it seems very likely that its position is driven mainly by the quoted average parameters which are shared by the whole considered population (i.e. metallicity, age etc., as said). So, taking into account the influence of $(B - V)_{peak}$ on the measured $B2/B + R + V$ we can hope to trace better the *real* color spread.

As a preliminary result note that, as already pointed out by F93, $(B - V)_{peak}$ do not correlate with $\log \rho_0$, while there is a correlation between $(B - V)_{peak}$ and $[Fe/H]$ (see FP93, Figure 8). Thus, at a zeroth approximation, $(B - V)_{peak}$ appears to trace the *first parameter*, $[Fe/H]$.

In Figure 2 we have plotted $B2/B + R + V$ *vs.* $(B - V)_{peak}$. Inspecting the plot, one immediately sees two regimes. The $B2/B + R + V$ index is quite insensitive to variations in $(B - V)_{peak}$ if $(B - V)_{peak}$ is larger than $\sim 0.3$mag. This is so because the the peak of the distributions are so red that the $B2/B + R + V$ index is unable to provide any significant ranking. For $(B - V)_{peak} < 0.3$ mag, the correlation between $B2 - R/B + R + V$ and $(B - V)_{peak}$ becomes evident and apparently linear. We performed thus a linear fit to the data within this linear range and calculated the residuals $[(B2/B + R + V)_{obs} - (B2/B + R + V)_{fit}]$. If our claim that the population of the blue tails is driven by a factor other than metallicity and age is correct, we must find that these residuals correlate with some other physical quantity.

In Figure 3, it is shown that the residuals display a clear-cut correlation with $\log \rho_0$. The Spearman's rank correlation coefficient is $s = 0.61$, and the probability that the involved parameters are actually uncorrelated is less than 1%. The observed dispersion of the relation can be completely accounted for by two different factors:

a) the observational errors which can well be, as said, larger than the figure quoted in column 7 of table 1 due to errors and insufficient completeness of the HB star photometry. Note that, while it seems unlikely that photometric errors do affect significantly the actual stellar counts, completeness can play a significant rôle when dealing with stars that can be as dim as the Turn Off of the considered cluster (see for instance the case of NGC 6752, Buonanno et al. 1986).

b) the quoted non-linear modulation of the response to mass loss settled by the metallicity, i.e. populations of different metallicity are expected to display quite different color-shift response to the same amount of mass loss (see F93 and DDRO). This effect must contribute in smearing the observed correlation, given the wide metallicity range $(-1.0 < [Fe/H] < -2.5)$ covered by the considered sample.

The only point whose deviation from the mean overall trend may be considered significant (the outcircled dot in fig. 3), represents the very metal poor cluster NGC7099 ($[Fe/H] = -2.3$). At present, we can just guess that its $B2/B + R + V$ measure has been probably underestimated because of incompleteness or of some unknown systematic error in the photometry.

From the above results one can thus draw the second conclusion: Unless cluster stellar density depends on age via a very special (unknown) connection, *some physical process which affects the evolution of stars living in a very dense environment must be at work within the cluster population.* Furthermore, this mechanism shows its effects mostly on the shape of the HB-distribution, enhancing the relative number of stars in the blue HB side, wherever the peak of the distribution itself is located (but, of course, with an "amplification factor" depending on the metallicity regime, see F93).

## 4. Discussion and future prospects

In the latest years, the understanding of the very blue Horizontal Branch stars has been growing in importance due to the impact it may have on topics like the quoted long-standing $2^{nd}P$ –problem, the connections between stellar evolution and dynamics (see Bailyn 1995), and the possible explanation of the UV-excess detected in the integrated light of many ellipticals and of spiral galaxy nuclei (see for references Greggio and Renzini 1990, Dorman et al. 1993, 1995, Bertelli et al. 1996). In these section we discuss briefly some of the spin-offs of our results and add few speculations related to some of the above-quoted topics.

1 The use of the HB morphology as a plain age indicator is no more justified, at least if only the *standard* parametrization (i.e. the $B - R/B + R + V$ index) is adopted. This is particulary true when dealing with "blue morphologies": in this cases the effects of old age cannot be distinguished from the effects of high density conditions. We demonstrated that a more suitable parametrization is clearly needed to disentangle the various effects.
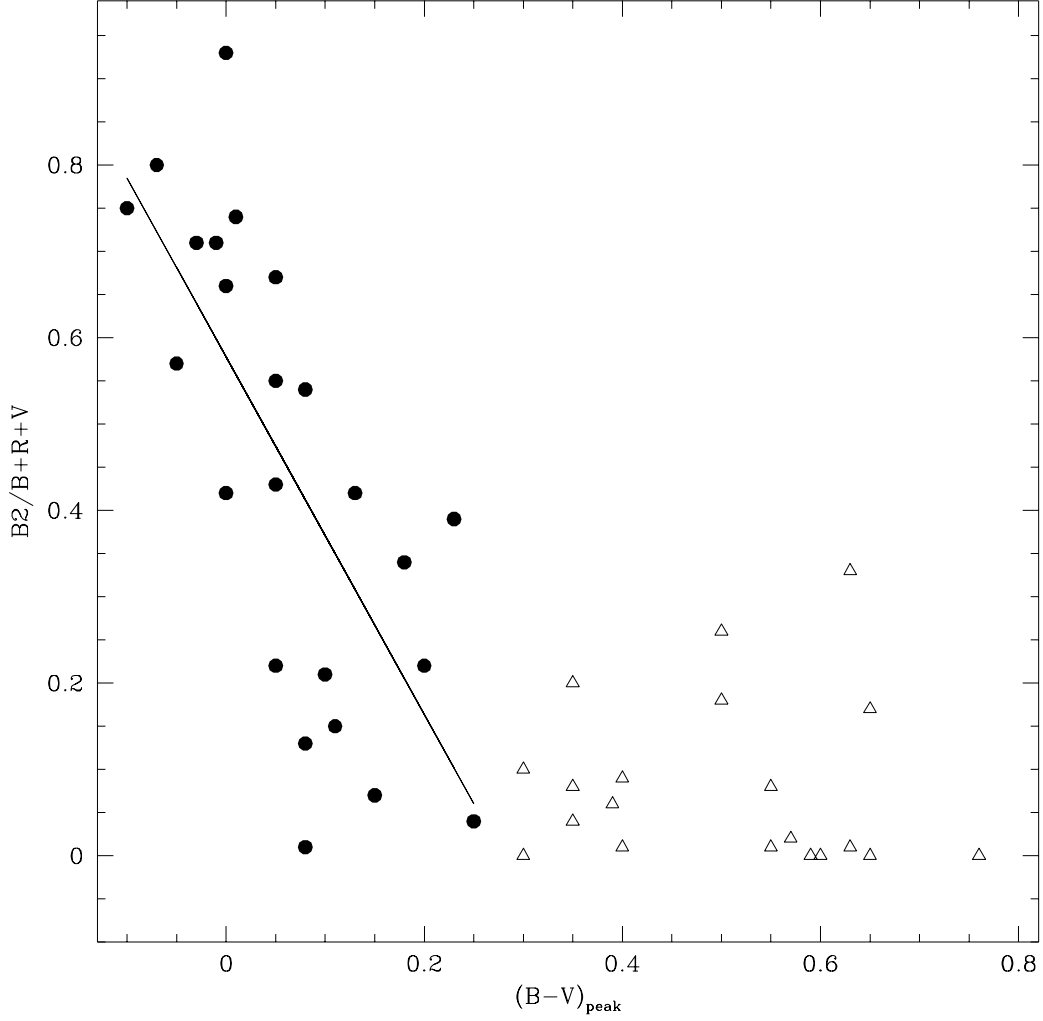
Fig. 2.— The index $B2/B + R + V$ versus the color of the peak of the Horizontal Branch distribution, $(B - V)_{peak}$ . Filled dots identify the clusters having a peak position sufficiently blue to make the "amplification effect" due to dense environment highly evident and yield a significant correlation between $(B - V)_{peak}$ and $B2/B + R + V$ . The line is just a linear regression fit to the data. Open triangles represent the clusters that have been excluded from the linear fit because of their red peak $((B - V)_{peak} > 0.3)$
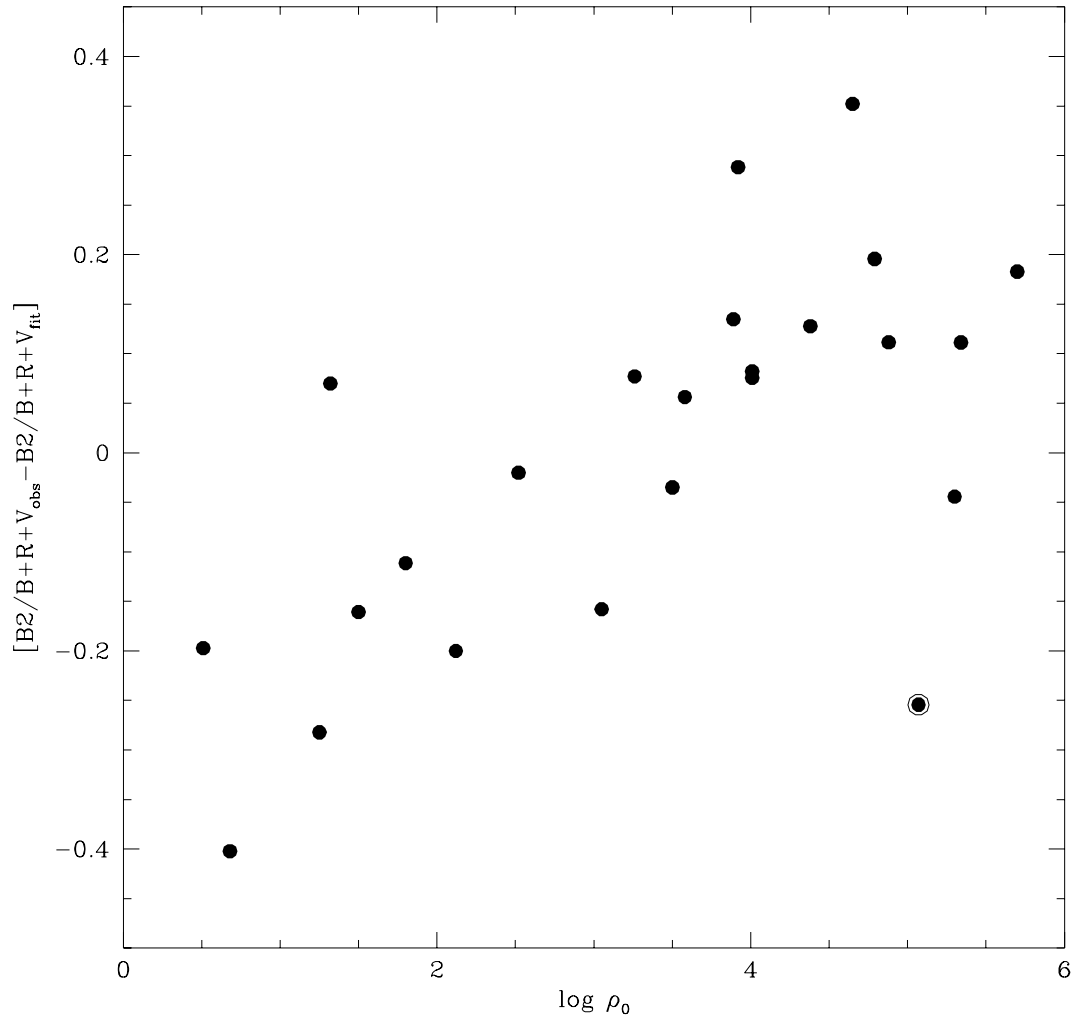
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Fig. 3.— The residuals of the fit shown in fig. 2 are found to correlate with $\log \rho_0$ . The Spearman's rank correlation coefficient is $s = 0.61$ and the probability that the two involved quantities are *uncorrelated* is less than 1%. The outcircled point corresponds to NGC 7099.

2 The behaviours of the peak of the HB distribution and of the *blue tail* are apparently decoupled (see fig.2, 3). This strongly suggests that the mechanism connecting *density* and *blue tails* is a rather random one, which seems *(a)* to be effective in perturbing only a fraction of the cluster stars, and *(b)* to act with different effectiveness on each of the perturbed star. Concerning the processes for the production of extremely blue HB stars, either the mechanisms reviewed by Bailyn (1995) (based on binary interactions) or the one proposed by BCFP85 seem consistent with the above-described scenario.

3 Assuming for instance that the process linking the production of blue HB objects and stellar density grows up in its efficiency in a continuous way with increasing density, one could also imagine that in some metal rich bulge clusters, particulary extreme density conditions (as, for example the occurence of a gravothermal collapse phase) may yield the amount of mass loss required to induce the *blue transition* of the whole HB, or of parts of it. If such clusters do exist, their HB has presumably a bimodal (or multi-modal, see DDRO) overall morphology, with the expected red clump populated by the stars "not-" or "less-affected" by this (unknown) mechanism which enhances mass loss, and a long blue tail (probably separated by a gap, see DDRO, Figure 7) populated by the "perturbed" stars. Consequently, it is also possible that some metal rich clusters already studied do display a blue HB population which has escaped detection because it is very faint in V, perhaps fainter than the Main Sequence Turn Off. The search for such features can surely be accomplished with the *HST* facilities, and the preliminary results presented by Piotto et al. (1996b) seem to be a first direct confirmation of the validity of this hypothesis.

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TABLE 1. Data for Galactic Globular Clusters

| Name | [Fe/H] | $\log \rho_0$ | $\frac{B2}{B+R+V}$ | $\frac{\sqrt{B+R+V}}{B+R+V}$ | $(B-V)_{peak}$ | Ref. |
|---|---|---|---|---|---|---|
| NGC 288 | -1.40 | 1.80 | 0.57 | 0.10 | -0.05 | 1 |
| NGC 362 | -1.28 | 4.75 | 0.01 | 0.10 | 0.55 | 2 |
| NGC 1261 | -1.31 | 2.98 | 0.01 | 0.06 | 0.63 | 3 |
| NGC 1851 | -1.29 | 5.16 | 0.17 | 0.10 | 0.65 | 4 |
| NGC 1904 | -1.69 | 4.01 | 0.55 | 0.08 | 0.05 | 5 |
| NGC 2419 | -2.10 | 1.50 | 0.21 | 0.09 | 0.10 | 6 |
| NGC 2808 | -1.37 | 4.63 | 0.33 | 0.04 | 0.63 | 7 |
| NGC 3201 | -1.61 | 2.63 | 0.20 | 0.08 | 0.35 | 8 |
| NGC 4147 | -1.80 | 3.58 | 0.22 | 0.13 | 0.20 | 9 |
| NGC 4372 | -2.08 | 2.18 | 0.68 | 0.09 | – | 10 |
| NGC 4590 | -2.09 | 2.52 | 0.04 | 0.10 | 0.25 | 11 |
| NGC 4833 | -1.86 | 3.05 | 0.42 | 0.10 | 0.00 | 12 |
| NGC 5053 | -2.58 | 0.51 | 0.07 | 0.15 | 0.15 | 13 |
| NGC 5272 | -1.66 | 3.54 | 0.10 | 0.07 | 0.30 | 14 |
| NGC 5286 | -1.79 | 4.19 | 0.51 | 0.08 | – | 10 |
| NGC 5466 | -2.22 | 0.68 | 0.01 | 0.11 | 0.08 | 15 |
| NGC 5694 | -1.91 | 4.01 | 0.66 | 0.17 | 0.00 | 16 |
| NGC 5824 | -1.85 | 4.65 | 0.26 | 0.08 | – | 10 |
| NGC 5897 | -1.68 | 1.32 | 0.71 | 0.13 | -0.03 | 17 |
| NGC 5904 | -1.40 | 3.92 | 0.39 | 0.08 | 0.23 | 18 |
| NGC 5986 | -1.67 | 3.24 | 0.52 | 0.13 | – | 19 |
| NGC 6093 | -1.64 | 4.79 | 0.67 | 0.15 | 0.05 | 20 |
| NGC 6101 | -1.81 | 1.57 | 0.10 | 0.11 | – | 21 |
| NGC 6121 | -1.33 | 3.91 | 0.01 | 0.08 | 0.40 | 22 |
| NGC 6218 | -1.61 | 3.26 | 0.80 | 0.09 | -0.07 | 10 |
| NGC 6229 | -1.54 | 3.46 | 0.26 | 0.11 | 0.50 | 23 |
| NGC 6254 | -1.60 | 3.50 | 0.75 | 0.13 | -0.10 | 19 |
| NGC 6266 | -1.28 | 5.34 | 0.42 | 0.06 | 0.13 | 10 |
| NGC 6284 | -1.40 | 4.65 | 0.93 | 0.09 | 0.00 | 20 |
| NGC 6287 | -2.05 | 3.99 | 0.00 | 0.12 | – | 24 |
| NGC 6341 | -2.24 | 4.38 | 0.54 | 0.09 | 0.08 | 15 |
| NGC 6333 | -1.78 | 3.58 | 0.09 | 0.10 | – | 25 |
| NGC 6362 | -1.08 | 2.23 | 0.08 | 0.11 | 0.55 | 26 |
| NGC 6397 | -1.91 | 5.70 | 0.74 | 0.08 | 0.01 | 27 |
| NGC 6522 | -1.44 | 5.53 | 0.34 | 0.09 | – | 28 |
| NGC 6535 | -1.75 | 2.25 | 0.50 | 0.25 | – | 29 |
| NGC 6584 | -1.54 | 3.19 | 0.01 | 0.08 | – | 30 |
| NGC 6626 | -1.44 | 4.71 | 0.67 | 0.13 | – | 31 |
| NGC 6638 | -1.15 | 4.02 | 0.09 | 0.21 | 0.40 | 32 |
| NGC 6656 | -1.75 | 3.67 | 0.28 | 0.10 | – | 33 |
| NGC 6681 | -1.51 | 5.56 | 0.87 | 0.10 | – | 10 |
| NGC 6712 | -1.01 | 3.09 | 0.02 | 0.13 | 0.57 | 34 |
| NGC 6717 | -1.32 | 4.60 | 0.76 | 0.24 | – | 10 |
| NGC 6723 | -1.09 | 2.71 | 0.18 | 0.10 | 0.50 | 35 |
| NGC 6752 | -1.54 | 4.88 | 0.71 | 0.07 | -0.01 | 36 |
| NGC 6809 | -1.82 | 2.12 | 0.15 | 0.07 | 0.11 | 37 |
| NGC 6864 | -1.32 | 4.53 | 0.06 | 0.09 | 0.39 | 38 |
| NGC 6934 | -1.54 | 3.43 | 0.09 | 0.08 | – | 10 |

TABLE 1. (continued)

| Name | [Fe/H] | $\log \rho_0$ | $\frac{B2}{B+R+V}$ | $\frac{\sqrt{B+R+V}}{B+R+V}$ | $(B-V)_{peak}$ | Ref. |
|------|--------|---------------|--------------------|-------------------------------|----------------|------|
| NGC 6981 | -1.54 | 2.26 | 0.08 | 0.09 | 0.35 | 10 |
| NGC 7006 | -1.59 | 2.42 | 0.04 | 0.11 | 0.35 | 18 |
| NGC 7078 | -2.17 | 5.30 | 0.43 | 0.07 | 0.05 | 15 |
| NGC 7089 | -1.58 | 3.89 | 0.34 | 0.10 | 0.18 | 38 |
| NGC 7099 | -2.13 | 5.07 | 0.22 | 0.11 | 0.05 | 20 |
| NGC 7492 | -1.51 | 1.25 | 0.13 | 0.18 | 0.08 | 39 |
| AM 1 | -1.01 | 0.32 | 0.00 | 0.19 | 0.60 | 40 |
| Pal 3 | -1.57 | 0.04 | 0.00 | 0.24 | – | 41 |
| Pal 4 | -1.28 | -0.24 | 0.00 | 0.22 | 0.59 | 42 |
| Pal 5 | -1.47 | -0.77 | 0.00 | 0.22 | 0.30 | 43 |
| Pal 12 | -1.14 | 0.68 | 0.00 | 0.38 | 0.76 | 44 |
| Pal 14 | -1.60 | -1.17 | 0.00 | 0.25 | 0.65 | 45 |
| Rup 106 | -1.80 | 1.22 | 0.00 | 0.15 | – | 46 |
| Arp 2 | -1.75 | -0.35 | 0.00 | 0.27 | – | 47 |
| IC 4499 | -1.50 | 1.50 | 0.01 | 0.08 | – | 48 |

References for Table 1.

(1) Buonanno et al. 1984; (2) Harris 1982; (3) Ferraro et al. 1993; (4) Stetson 1981; (5) Ferraro et al. 1992; (6) Racine & Harris 1975; (7) Ferraro et al. 1990; (8) Lee 1977b; (9) Sandage 1955; (10) Brocato et al. 1996; (11) Walker 1994; (12) Menzies 1972; (13) Sarajedini 1995; (14) Buonanno et al. 1994; (15) Buonanno et al. 1985; (16) Ortolani & Gratton 1990; (17) Ferraro, Fusi Pecci & Buonanno 1992; (18) Buonanno, Corsi & Fusi Pecci 1991; (19) Harris, Racine & de Roux 1976; (20) Piotto 1996a; (21) Sarajedini 1991; (22) Lee 1977a; (23) Iannicola 1996; (24) Stetson & West 1994; (25) Janes & Heasley 1991; (26) Alcaino 1976; (27) Alcaino et al. 1987; (28) Barbuy, Ortolani & Bica 1994; (29) Liller 1980; (30) Sarajedini & Forrester 1995; (31) Alcaino ; (32) Alcaino & Liller 1983; (33) Alcaino 1983; (34) Cudworth 1988; (35) Menzies 1974; (36) Buonanno et al. 1986; (37) Lee 1977c; (38) Harris 1975; (39) Buonanno et al. 1987; (40) Aaronson, Schommer & Olzewski 1984; (41) Gratton & Ortolani 1984; (42) Christian & Heasley 1986; (43) Sandage & Hartwick 1977; (44) Gratton & Ortolani 1989; (45) Harris & van den Bergh 1984; (46) Buonanno et al. 1990; (47) Buonanno et al. 1994; (48) Ferraro et al. 1995.